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VITRIFIED BRICK AS A PAVING MATERIAL FOR COUNTRY ROADS.

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INTRODUCTION.

A clay product closely resembling our present-day brick was among the earliest materials used for paving streets and roads. The first brick pavement constructed in this country, however, dates back no further than 1872; and to Charleston, W. Va., belongs the distinction of having been the first American city to employ brick for paving.

For a number of years after being introduced into this country the use of paving brick was principally confined to city streets, and, owing to frequent inferiority in the quality of the brick and lack of care in construction, very few of the early pavements proved satisfactory. Even now, after the experience of 40 years has demonstrated that it is entirely practicable to construct satisfactory brick pavements when proper care is exercised, and that much waste results from the use of poor materials or faulty construction, instances can frequently be found where brick pavements have wholly or partially failed from causes which might easily have been prevented.

Country roads paved with vitrified brick are becoming quite common in many of our States, and, owing to the general satisfaction which these roads are giving when properly constructed, it is probable that their mileage will continue to increase rapidly. The principal advantages which brick roads possess may be stated briefly as follows: (1) They are durable under heavy traffic conditions; (2) they afford easy traction and good foothold for horses; (3) they are easily maintained and kept clean; and (4) they present a very pleasing appearance.

The principal disadvantage is the high first cost. The defects which frequently result from lack of uniformity in the quality of the brick or from poor construction are usually to be traced indirectly to an effort to reduce the first cost or to a popular feeling that local materials should be used, even when of inferior quality.

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This bulletin purposes to furnish information relating to the construction of brick roads, and to supply suggestions for aiding engineers in preparing specifications under which such work may be satisfactorily performed. One of the most essential features of the construction of brick pavements is the selection of the brick, since the success or failure of such pavements depends to a large extent on the character of the material used. In order that the significance of the varying physical characteristics observed in brick manufactured under different conditions may be more readily understood, a brief discussion of the raw materials and processes used in the manufacture of brick will be given.

THE RAW MATERIALS.

Paving brick are made from shales and fire clays. The "lean" or less refractory varieties of these materials, which are found in the carboniferous deposits broadly distributed throughout the United States, are best adapted for this purpose.

Shales frequently occur in such quantity and are so located that they may be readily excavated by means of a steam shovel or other mechanical device. Occasionally, however, the deposits are comparatively thin and underlie other material, making it necessary that they be mined. Fire clays are usually found interstratified with coal deposits which may or may not be workable, and must, therefore, generally be mined. The principal difference between fire clays and shales, in so far as the manufacture of brick is concerned, is essentially a difference of color in the finished product. The shales always contain iron in some form, and brick made of shale are usually red. Fire clays are free from iron and should produce a light-colored brick. Some low-grade fire clays, however, may be darkened by certain firing conditions too complicated to be discussed in detail here.

Shales and fire clays as they occur in nature are not always well suited for use in the manufacture of paving brick, but must frequently be subjected to some modifying treatment before being used. In general, deposits of these materials occur in layers or strata, and the different strata are almost always slightly dissimilar in both physical and chemical composition. By carefully mixing the materials from different strata or from different parts of the bank, therefore, a resulting material of the desired character may usually be obtained. It not infrequently happens, however, that in order to secure the best results sand or surface clay must be added in an amount depending on the relative "leanness" or "fatness"[1] of the material used. In this connection it may be noted, also, that a chemical analysis of a given fire clay or shale does not necessarily

[1] "Leanness" and "fatness" refer respectively to the lesser or greater amount of silica present in the material.

indicate its fitness or unfitness for paving brick. The reason for this is that the quality of the brick after "firing" is no less dependent on the physical arrangement of the minerals than on the chemical composition of the material.

THE MANUFACTURE.

The general processes of manufacture are the same for both fire clays and shale. The raw material in either case is crushed to comparatively small fragments and conveyed by some convenient means to a grinding machine, known in the industry as a dry pan. Briefly, this machine consists of a solid iron plate, approximately 5 feet in diameter, surrounded by a perforated iron surface about 2 feet wide. Outside the perforated surface is a rim some 15 inches in height which serves to prevent the material from escaping otherwise than through the perforations. Upon the solid plate rest two massive crushers or mullers, each weighing from $2\frac{1}{2}$ to 3 tons. The pan is revolved rapidly, causing the mullers to rotate by friction. The material is ground between the mullers and the plate and thrown out by centrifugal force toward the rim, where it escapes through the perforated surface into an elevator, by means of which it is conveyed to the screens.

The particles too large to pass the screens, which should not exceed three-sixteenths inch in mesh, are returned to the dry pan, while the screened material is passed to the mixing machine or pug mill by means of conveyors. In the pug mill, water is admixed with the clay to form a stiff mud, which is fed continuously into the brick machine proper.

The brick machine is an extremely heavy mechanism. It consists essentially of an auger or propeller conveyor, a tapering barrel, and the die or former. The material is forced by means of the auger conveyor into the tapering barrel, which terminates in the die, and issues from the die in a solid column under heavy pressure. For "side-cut" brick this column is approximately $4\frac{1}{2}$ inches by 10 inches in cross section, and the brick are formed by cutting through the column, by means of an automatic device, at intervals of about $3\frac{1}{2}$ inches. For "end-cut" brick the column has a cross section approximately 4 inches by $4\frac{1}{2}$ inches and is cut into sections about 10 inches long.

Paving brick, whether end or side cut, have usually in the past been re-pressed. This process smooths and rounds the corners, and forms on one side of each brick small lugs or projecting trademarks which serve to produce uniform spacing between the courses of the pavement. Suitable lugs may also be formed at the time the brick are cut, however, and the process of re-pressing is then omitted. Much discussion has taken place as to which of these methods pro-

duces the better brick, and each method has many advocates. Entirely satisfactory pavements have been made from both re-pressed and unre-pressed brick, however, and it is very doubtful if the failures which have been observed in connection with either type could rightfully be attributed to this particular feature in the process of manufacture.

Special shapes, such as nose bricks for use next to car tracks, and hillside block, which have one side thicker than the other and which are used on steep grades in order to give the pavement a rough surface, may be made either by special die or special re-press molds.

The next step in the process of manufacture consists in drying the brick. In a properly systematized plant the brick are stacked upon drier cars as they leave the presses in such manner as to permit a free circulation of air between them. The loaded cars are immediately run into a tunnel drier, the temperature of which is maintained at about 100° F. at the entering end. As cars containing "green" brick enter one end of the tunnel, which is usually more than 100 feet long, other cars containing dry brick are being removed at the opposite end. Air circulation in the dryer is effected by means of fans or high stacks. During drying the brick lose an amount of moisture equivalent to from 15 to 20 per cent of their own weight.

The brick leave the dryer ready for burning, which is the last and undoubtedly the most important step in the process of manufacture. Upon the burning depends largely the quality of the finished product, and it requires the greatest skill so to regulate the temperatures and firing periods as to obtain the best results from a given material. Experience alone can demonstrate the manner in which the burning must be modified in order to suit varying sets of conditions. The kilns in which the burning is done are made of brick and are provided with numerous furnaces. The brick are placed in the kilns so as to permit a free circulation of the gases of combustion and the heated air.

PHYSICAL CHARACTERISTICS.

GENERAL REQUIREMENTS.

Paving brick should be uniform in size, reasonably perfect in shape, and free from ragging, due to friction in the die, or kiln marks, caused by impressions from overlying brick in burning. They should be tough in order to resist crushing, hard in order to resist abrasion, and uniformly graded in order that the pavement may wear evenly. Each brick should be homogeneous in texture and free from objectionable laminations or seams. Fire cracks, caused by too rapid firing, should be limited in number and extent, and the entire brick should be vitrified and should contain neither unfused nor glassy spots.

COLOR.

The color is a valuable guide in inspecting brick from the same plant, but it is of little importance when the brick to be compared are from different factories. For brick manufactured from a particular raw material the color indicates, in a measure, the temperature to which they have been subjected, provided they have been burned under identical conditions. Ordinarily, the darker the color, the higher the temperature and, presumably, the better the brick. The surface color of brick may be very misleading, however, and the color of the interior should be used in making comparisons.

SPECIFIC GRAVITY.

The specific gravity of paving brick was formerly considered of importance in judging their fitness for use in pavements. It has since been generally conceded, however, that a knowledge of the specific gravity is of comparatively little value. The specific gravity of shale brick is ordinarily between 2.20 and 2.40, and of fire-clay brick between 2.10 and 2.25.

ABSORPTION.

The absorptive power of brick, like their color, is a matter of very slight importance, except for comparing specimens manufactured under identical conditions. It is true that the porosity of the brick increases with the power of absorption, but it is very doubtful if any paving brick possessing an objectionably high absorptive power could pass even a very casual inspection. In other words, a high degree of porosity always manifests itself in other ways more clearly than in the ability of the brick to absorb water.

CRUSHING STRENGTH.

The crushing strength of good paving brick varies from 10,000 pounds to 20,000 pounds per square inch when the load is applied uniformly over the entire top surface of the test specimen, and may be much greater if the area over which the load is applied is less than that of the top surface. Since paving brick in use are seldom required to withstand a pressure of more than about 2,000 pounds per square inch and since inferior brick may possess relatively very high resistance to crushing, a knowledge of the crushing strength is clearly of little value in comparing the relative excellence of different makes of brick. It is, therefore, usually considered unnecessary to specify a definite requirement as to the crushing strength of paving brick.

TESTING THE BRICK.

Definite methods of testing paving brick have been in general use for only a comparatively few years and have only recently undergone a pronounced change. The object of all tests is to determine

whether or not a given quality of brick is suitable for use in constructing pavements and to furnish a basis for comparing different classes of brick. The methods have, therefore, been repeatedly changed, not only in order to make the results obtained indicate more definitely the quality of the brick, but also with a view to establishing uniformity, so that results obtained in different laboratories may be intelligently compared. A discussion of the most important tests follows in more or less detail.

FIELD TEST.

The general appearance of a paving brick is, to an experienced eye, a valuable indication of its quality, and will frequently suggest the advisability of applying routine tests to some particular part of a shipment. Unfortunately, however, the knowledge gained from experience with one kind of brick can not be safely relied upon in inspecting other brick made by a different process or from a different class of raw material. A further limitation to this method of testing lies in the fact that the results obtained do not admit of numerical evaluation, and can not, therefore, be very accurately described. This test is nevertheless valuable, and since no apparatus other than a hand hammer is needed, it can always be employed.

The test consists simply in making a careful inspection of the brick individually and collectively. The size is tested by making measurements, the shape by arranging a number of brick in the order in which they are intended to be placed, and the quality by an examination of both the exterior and interior of a number of samples.

TRANSVERSE TEST.

The transverse strength of a brick is determined by supporting it upon two knife edges and applying a load on the opposite side and midway between the supports by means of a third knife edge. The load is gradually increased until rupture occurs, and the result of the test is expressed in terms of the ratio $\frac{3\ \mathrm{P}\ 1}{2bd^2}$, called the modulus of rupture. In the above ratio P represents the breaking load in pounds, while 1, b, and d represent, respectively, the distance between supports, the breadth of the specimen, and the depth of the specimen, all measured in inches.

The modulus of rupture for good paving brick usually lies between 2,000 and 3,000, and frequently varies considerably even with carefully selected specimens which have been manufactured under identical conditions. In making this test a considerable number of specimens should be used, and the requirements concerning the transverse strength should be no less definite as to uniformity in the results of the test than as to the average modulus of rupture.

RATTLER OR ABRASION TEST.

The rattler or abrasion test is undoubtedly the most important of the tests made on paving brick at present. In making this test the specimen brick are subjected to destructive influences very similar to those encountered in actual service, and the results obtained, therefore, indicate very closely the effect which traffic may be expected to produce on a pavement constructed of similar brick. The methods of making the test, of which there were formerly a great many, have undergone repeated changes in order that service conditions may be more nearly approached and also in an effort to bring about uniformity, so that the results obtained may be of the greatest possible scientific value. The method which has been lately recommended by the subcommittee on paving brick of the American Society for Testing Materials may be briefly described as follows:

The apparatus necessary for making the test, ordinarily called the rattler, consists of a 14-sided barrel of regular polygonal cross section supported on a suitable frame and fitted with the necessary driving mechanism. The staves, each of which forms a side of the barrel, are made of 6-inch 15.5-pound structural steel channels $27\frac{1}{4}$ inches long. These staves are double bolted to the cast-iron heads of the barrel, which are provided with slotted flanges for holding the bolts. Cast-iron wear plates are bolted to the inside of the barrel heads. The outside diameter of the barrel is $28\frac{3}{8}$ inches.

In this barrel is placed what is known as the abrasive charge. This charge consists of two sizes of cast-iron spheres having respective diameters of $3\frac{3}{4}$ inches and $1\frac{7}{8}$ inches and weighing, respectively, 7.5 pounds and 0.95 pound when new. Ten of the larger spheres are used, and the number of the smaller spheres is made such that the weight of the entire charge will approximate 300 pounds. The individual larger spheres are discarded whenever their weight falls to 7 pounds or less and the smaller spheres when they become sufficiently worn by usage to pass through a circular opening having a diameter of $1\frac{3}{4}$ inches.

The test is made by placing a charge of ten representative brick, which have been previously dried at a temperature of 100° F. for at least three hours, in the barrel together with the abrasive charge, and then revolving the rattler 1,800 times. The number of revolutions per minute is not permitted to fall below $29\frac{1}{2}$ nor to exceed $30\frac{1}{2}$, and the operation is made continuous from start to finish.

The results of the test are reckoned in terms of the loss in weight sustained by the brick, and this loss is expressed as a percentage of the original weight of the brick tested. In determining the loss in weight, no piece of brick which weighs less than 1 pound is considered as having withstood the test.

Good paving brick will ordinarily lose from 17 per cent to 22 per cent of their original weight in the rattler test, and specifications concerning this loss should be prepared with a view to the character of the traffic for which the pavement is designed. Some reasonable requirement as to the loss sustained by any individual brick should also be made. This loss should ordinarily not exceed 25 per cent, and under severe traffic conditions a smaller percentage should be required.

CONSTRUCTION.

PREPARING THE SUBGRADE.

In forming a roadbed upon which a brick pavement is to be constructed, the essential features to be considered are (1) thorough drainage, (2) firmness, (3) uniformity in grade and cross section, and (4) adequate shoulders.

Thorough drainage can be secured for any particular road only by means of a careful study of the local conditions which affect the accumulation and "run-off" of both the surface and ground water. These conditions vary considerably even in the same locality, and no set of rules can be given which would cover all cases. For example, the material composing the roadbed may be springy, and in this case tile underdrains will probably be necessary. On the other hand, extremely flat topography may make it necessary to elevate the grade considerably above the surrounding land. The nature of the soil, the topography, and the rainfall must all be considered if a system of drainage is to be planned properly.

The second requirement, firmness, can be secured only after the road has been properly drained. Soils which readily absorb moisture can not be properly drained in wet weather and should not be permitted to form a part of the subgrade. In order that the subgrade may be unyielding, it is also necessary that the roadbed be thoroughly compacted. In forming embankments, the material should be put down in layers not over 8 inches thick, and each layer should be thoroughly rolled. In excavation care should be exercised, if the material is earth, not to permit plows or scrapers to penetrate below the subgrade. The subgrade in both excavation and embankment should be brought to its final shape by means of finish grading with picks and shovels and rolling.

When completed the subgrade should be uniform in grade and cross section, or otherwise the foundation must be made unnecessarily thick where depressions occur, in order that its grade and cross section may be uniform and its thickness not less at any point than that required. The subgrade should be repeatedly rolled and reshaped until the desired shape is secured. The curbs, which should be set before the final finishing, may be made to serve as a guide for this work.

The shoulders, while essentially a part of the road surface, should be constructed at the same time that the subgrade is formed. This is necessary in order that the curb may be properly supported while the pavement is being laid and rolled. The shoulders should never be less than 4 feet wide and should consist of some material which compacts readily under the roller and which does not readily absorb water. Not infrequently one of the shoulders is made sufficiently wide to form an earth roadway parallel to the brick pavement. Such an arrangement serves to relieve the pavement of considerable traffic during favorable seasons and thereby adds greatly to its life. The general method of constructing shoulders for brick roads is not essentially different from that employed for other types of pavements.

CURBING.

All brick pavements should be supplied with strong, durable curbing, both on the sides and at the ends. Otherwise, the marginal brick will soon become displaced by the action of traffic, and their displacement will of course expose the brick next adjoining, so that deterioration will soon spread over the entire pavement. Properly constructed curbing, on the other hand, will hold the pavement as in a frame and enable the brick to present their combined resistance to the destructive influences of traffic.

Satisfactory curbs may be constructed of stone, Portland cement concrete, or vitrified clay shapes made especially for this purpose. Wood has also been used for curbs to a limited extent, but when it is considered that the life of a brick pavement under ordinary conditions should far exceed the life of any wood curb which might be devised, the economy of employing a more durable material is readily apparent.

Stone curbing may be made from any hard tough stone which is sufficiently homogeneous and free from seams to admit being quarried into blocks not less than 4 feet long, 5 inches thick, and 18 inches deep. On account of their ordinarily homogeneous structure, granite and sandstone are probably more used for curbs than any other kind of stone.

All stone curbing should be hauled, distributed, and set before the subgrade is completed. The individual blocks should be not less than about 4 feet long except at closures, and should have a depth of from 18 to 36 inches, depending on traffic conditions and on whether the curb is to project above the surface forming one side of the gutter. The neat thickness need never be greater than 6 inches and, where the traffic conditions are not severe and the quality of the stone is good, a thickness of 4 inches will ordinarily prove satisfactory. Stone curb should always be set on a firm bed of

gravel, slag, or broken stone, not less than 3 inches thick, and should be provided with a backing of the same material on the shoulder or sidewalk side. Figure 1 shows a typical stone curb in place.

Where suitable stone is not readily available or when from any cause the cost of stone curbing would prove excessive, a curb constructed of Portland cement concrete may frequently be advantageously used. Concrete curbs may be constructed alone or in combination with either a concrete gutter or a concrete foundation. The advisability of constructing the curb in combination with the foundation, however, is doubtful. Very little is saved by such an arrangement, and the small saving is probably even more than offset by the additional difficulty involved in preparing the subgrade

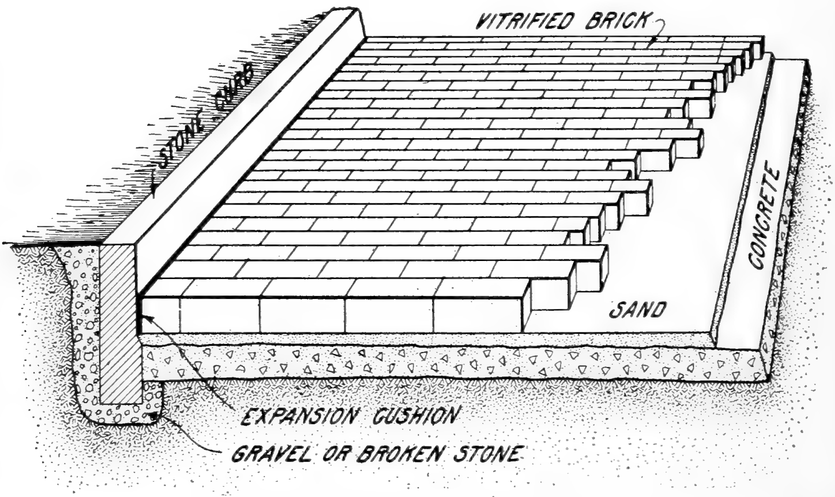


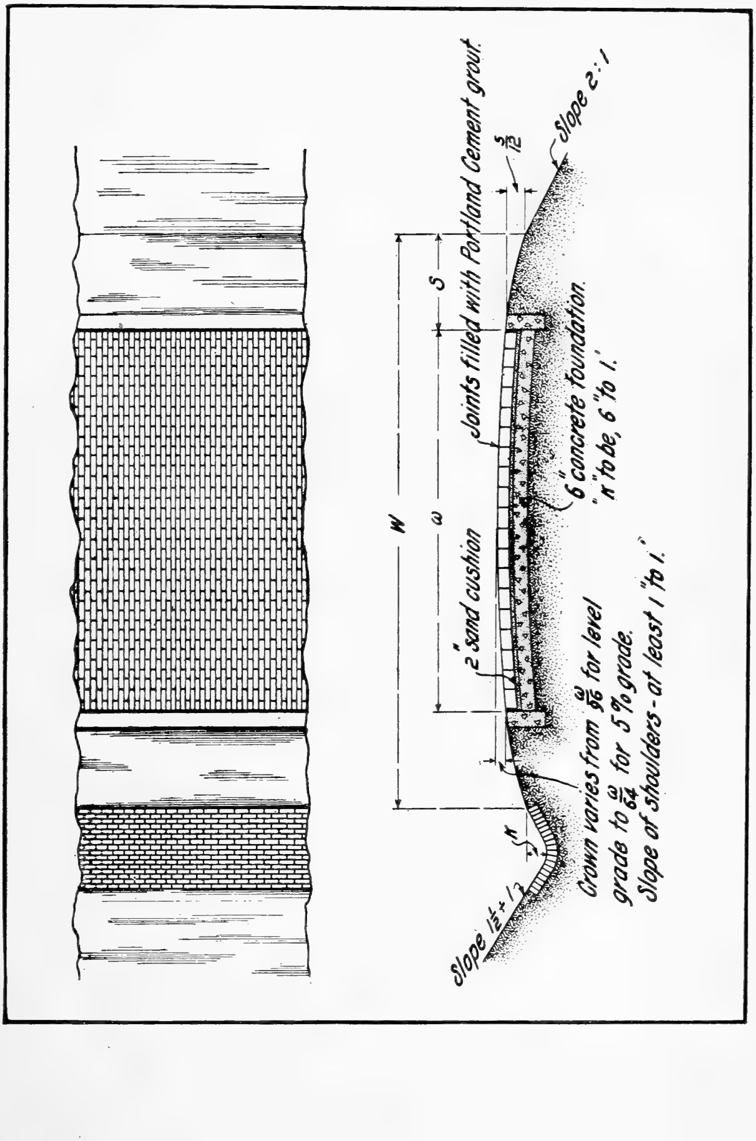
FIG. 1.—Proper method of constructing stone curb.

without the curb to serve as a guide. Concrete curbs should have approximately the same cross-sectional dimensions as stone curbs and should be constructed in sections not exceeding about 7 or 8 feet in length. Figures 2 and 3 and Plate I show the three common methods of constructing concrete curbs.

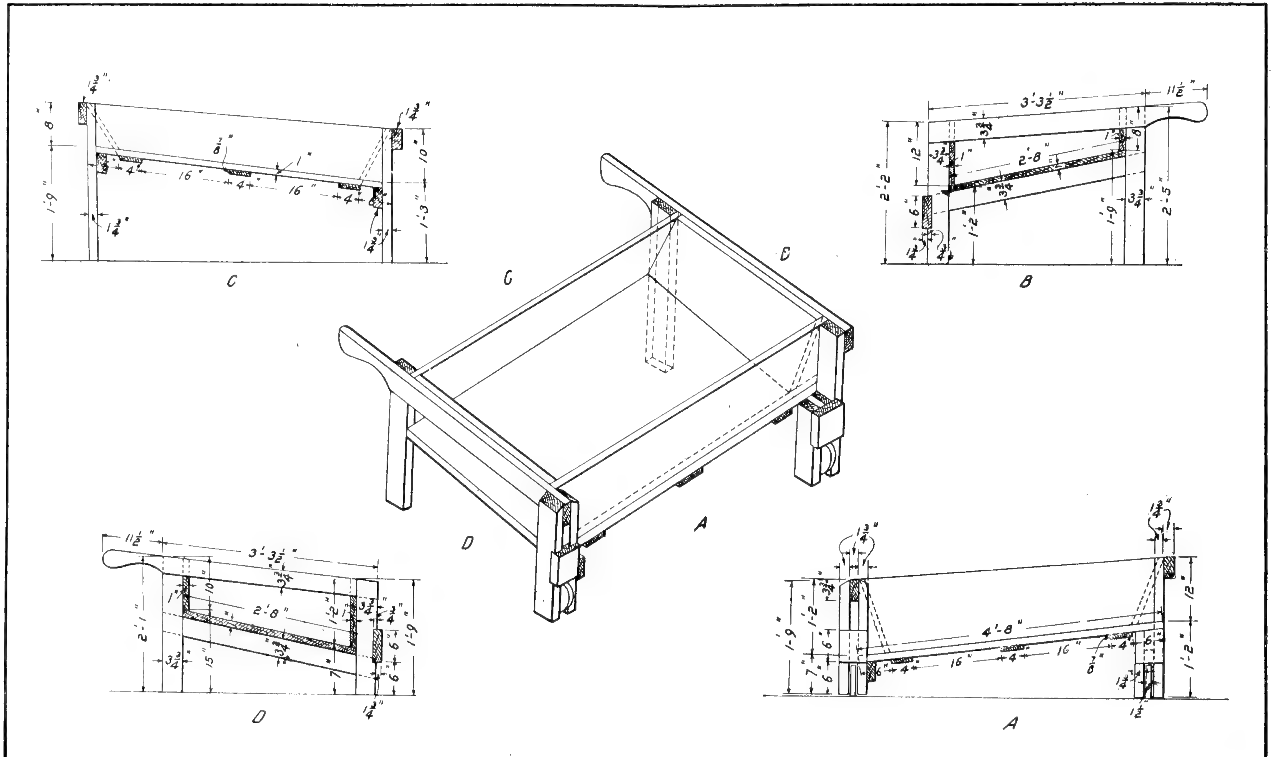
Vitrified clay curbing should be set in much the same manner as that described for stone curbing. The principal additional requirement is that, since vitrified clay is a lighter material than stone and the curb sections are ordinarily shorter, the bedding must be made correspondingly more secure in order to prevent displacement.

THE FOUNDATION.

A firm, unyielding foundation is one of the most essential features of a brick pavement. This fact can be more readily appreciated when it is considered that the surface of a brick pavement is made up



TYPICAL PLAN AND SECTION FOR BRICK ROAD.



PLAN FOR GROUT BOX HAVING LOW CORNER.

of small individual blocks, any one of which might be easily forced down, causing unevenness in the surface, if the foundation were poor; and since the ability of the pavement to resist wear depends very largely on the smoothness of the surface, every reasonable precaution should be taken to prevent any unevenness from developing.

The proper type of foundation depends largely on the material composing the subgrade and the character of traffic for which the road is designed. Where the traffic is comparatively light and the subgrade is composed of some firm material which does not readily absorb water, a very satisfactory foundation may be constructed of broken stone or gravel filled with sand. Where the traffic is comparatively heavy, however, or where the material composing the subgrade is defective in any way, a monolithic concrete foundation should be used. Foundations consisting of a course of brick laid flat upon a

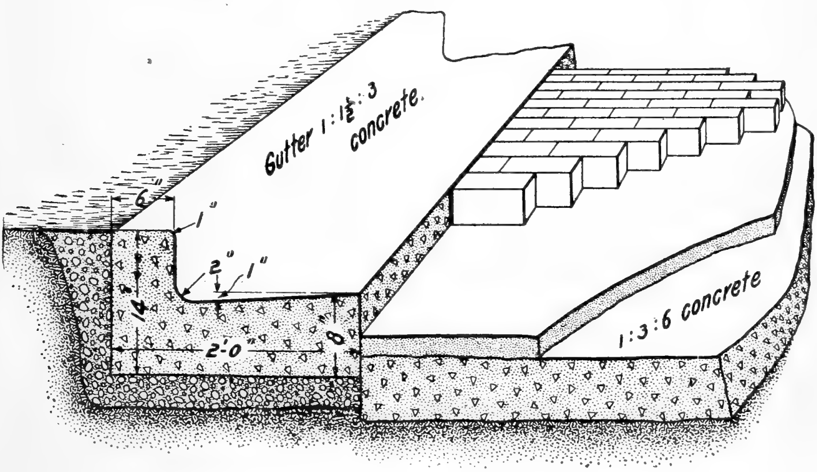


Fig. 2.—Concrete curb and gutter combined.

previously compacted layer of gravel or broken stone have also been extensively used, and pavements constructed upon foundations of this kind, ordinarily called "double-layer" pavements, have in general proved satisfactory, even where the subgrade was composed of an inferior material. At the present time, however, such foundations can rarely be constructed at less cost than the more durable concrete foundations, and they will therefore be given no further consideration here.

Gravel and broken-stone foundations may be spread in one or more courses, each of which should be from 5 to 9 inches thick before compacting. The materials used should conform in the matter of physical characteristics to the ordinary requirements for similar materials used in constructing macadam roads; that is, the stone or gravel should be clean, hard, tough, and durable, and should be graded in size between certain reasonable, fixed limits. It should be

uniformly spread on the road, either from dumping boards by means of shovels or from wagons especially designed to spread the material as it is being dumped. Where whole loads are dumped in one place and then spread out to the required depth, it is very difficult to obtain uniform density. Usually those spots where the loads are dumped are more densely compacted than the rest of the foundation, and this lack of uniformity very soon manifests itself by producing unevenness in the surface of the pavement. Broken-stone and gravel foundations should be compacted in the usual manner by rolling with a power roller weighing not less than about 10 tons, and sufficient clean, coarse sand to fill the voids should be spread and flushed

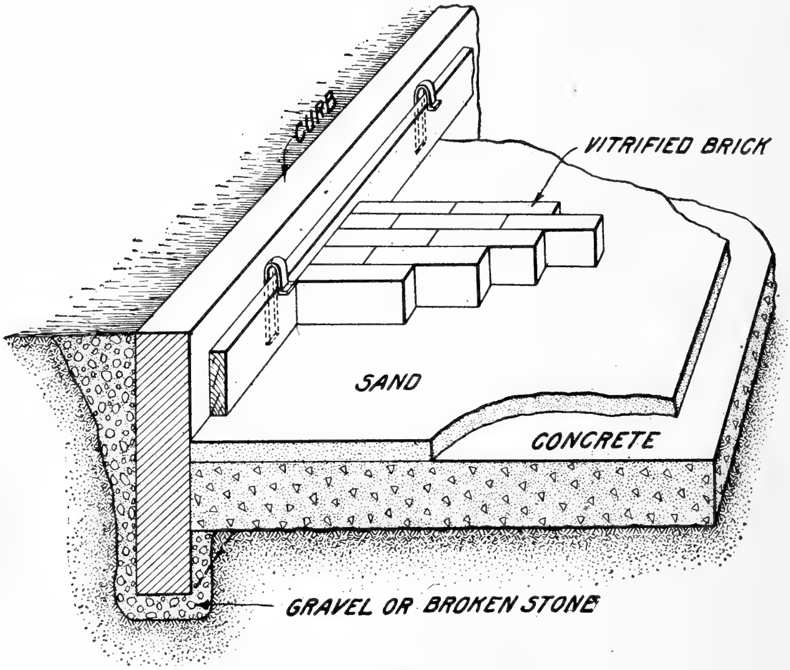


FIG. 3.—Making provision for expansion joint.

into the foundation while the rolling is in progress. When complete the foundation should present a surface uniform in grade and cross section and parallel to the proposed surface of the finished pavement.

Concrete foundations are unquestionably better adapted for brick pavements than any other type. They are practically monolithic in form, nearly impervious to water, and possess a relatively high crushing strength. All of these qualities may be obtained with a relatively "lean" concrete if the subgrade has been properly prepared. Under ordinary circumstances a satisfactory foundation may be constructed of concrete composed of 1 part of Portland cement, 3 parts of sand, and from 5 to 7 parts of broken stone or screened gravel.

The sand should be clean and well graded in size, and the stone or gravel should conform to the requirements given above in connection with the discussion of foundations constructed of those materials.

Foundations for brick pavements have also been constructed of timber boards laid on sand, and in some instances of sand alone. These foundations have seldom proved satisfactory for any great length of time, however, and can, therefore, be economically used only when the pavement is to be constructed of an inferior grade of brick.

SAND CUSHION.

Since it is practically impossible to construct an absolutely smooth foundation, and since there is always a slight variation in the size of paving brick, owing to slight differences in the amount of shrinkage at the time of burning, it is necessary to provide an adjustable cushion of some kind between the foundation and the brick for correcting these slight irregularities, in order to secure an even surface and a uniform bearing for the brick. Sand has been found a most satisfactory material of which to construct this cushion, and is almost exclusively used for this purpose. The proper thickness for the sand cushion will of course depend on the extent of the inequalities above mentioned. Two inches is the most usual thickness, however, and this thickness has generally proved very satisfactory.

The sand used in the cushion should be clean, free from pebbles, and preferably fine grained. If dirt or vegetable matter is present, it will soon be leached out and cause unevenness to develop in the pavement, while pebbles prevent the brick from securing a uniform bearing, and ultimately produce the same result. Fine sand adjusts itself to the shape of the brick more readily than coarse sand, and is, therefore, given preference. It is also important that the sand should be dry when spread, because a comparatively small amount of moisture increases the volume of fine sand considerably, and moisture when present is not, as a rule, uniformly distributed. Even if it were uniformly distributed at the start, some spots would dry out more rapidly than others while the spreading was under way, and a lack of uniformity would thus be produced in the cushion.

In forming the cushion the sand is uniformly spread over the foundation to a depth slightly in excess of that desired, and is then smoothed off by drawing over it a template shaped to conform with the cross section of the finished pavement. The length of the template is ordinarily made equal to the width of the pavement where this is less than about 25 feet, and equal to half the width for wider pavements. Timber guides may be laid in the same direction as the pavement for the template to slide on, or the curbs may be made to serve as guides where this is convenient.

After the cushion is spread and uniformly "struck off" with the template to a depth slightly in excess of that required, it should be

thoroughly compacted by rolling with a hand roller weighing from 300 to 400 pounds, and any depressions which form should be corrected. This is necessary in order to secure uniform density and to prevent unequal settlement of the surface.

HANDLING AND LAYING THE BRICK.

The brick may all be hauled and piled at convenient intervals along the sides of the roadway before grading is begun, or, if more convenient, they may be delivered as needed on the work. Hauling over the finished pavement with wagons until it is complete and opened to traffic should be avoided. If the brick are delivered on the work as needed, they should be unloaded from the wagons outside of the curb and carried to the pavers, either by hand or in wheelbarrows. Plank trackways should also be provided over the newly laid pavement for the wheelbarrows when they are used.

The brick should in all cases be uniformly piled by hand on the new pavement conveniently close for the pavers, and each brick should be so placed that the regular operation of picking it up and placing it in the pavement will bring the best edge up. This method of handling the brick requires somewhat more labor than the common method of dumping them from wheelbarrows, but it eliminates to a great extent the practice of picking out and turning over chipped or kiln-marked brick, after the pavement is laid. This is very objectionable on account of the disarrangement of the sand cushion, which is frequently occasioned.

The brick should be laid on edge and in uniform courses running at right angles to the line of the pavement, except at intersections; and in order to "break the joints" each alternate course should begin with a half brick. In laying the brick the pavers stand on the pavement already laid and, beginning at the curb each time, carry across as many courses together as they can conveniently reach. The courses should be kept straight and close together, and if necessary each block of eight or ten courses should be driven back by means of a sledge and a piece of straight timber approximately 2 by 4 inches by 5 or 6 feet long. The brick should also be laid close in the courses and should be crowded together, if necessary, after a course is laid, by means of a crowbar inserted at the curb.

After the brick are laid, the pavement should be carefully inspected for the purpose of detecting soft or otherwise defective brick. Misshapen or broken brick may be detected by the eye alone and the soft brick by sprinkling the pavement with water. The soft brick appear comparatively dry while the water is being applied and comparatively wet after the sprinkling is stopped. All defective brick should, of course, be replaced by others which meet the requirements of the specifications.

TRUING THE SURFACE.

After the pavement has been laid and all defective brick have been replaced to the satisfaction of the engineer, the next step is to sweep the surface clean and smooth out all inequalities by means of ramming or rolling. The rolling should be done with a power roller weighing from 3 to 5 tons, and the pavement should ordinarily be rolled in both the longitudinal and transverse directions. The longitudinal rolling should be done first and should begin at the curbs and progress toward the crown. The roller should pass at least twice over every part of the pavement in both transverse and longitudinal directions. In order to neutralize any tendency which the brick may have to careen under the roller, the number of forward trips over any part of the pavement, if more than two trips are required, should equal the number of trips backward over the same part.

In places where it is impracticable to use the roller for truing the surface, such, for example, as along the curbs or concrete gutters or around manholes, the brick should be brought to a true surface by means of ramming. For this purpose a wooden rammer loaded with lead and weighing from 80 to 100 pounds may be used. The blows of the rammer should not fall directly upon the brick, but should be transmitted through a 2-inch board laid parallel to the curb.

After the pavement has been trued up, as described above, it should be inspected again for broken or otherwise damaged brick, and also for those which have settled excessively, owing to some lack of uniformity in the sand cushion. All defects should be corrected and the areas distributed in making the corrections should be brought to a true surface by tamping.

FILLING THE JOINTS.

In order to keep the brick in proper position and protect the edges from chipping, it is necessary to fill the joints with some suitable material before the road is opened to traffic. The materials which have in the past been most commonly used for this purpose are sand, various bituminous preparations, and a grout made of equal parts of Portland cement and fine sand mixed with water.

Sand is the least expensive of these materials, but there are several very serious objections to its use as a joint filler: (1) It does not protect the edges of the brick; (2) it is easily disturbed in cleaning the pavement and is likely to be washed out by rain on steep grades; (3) it does not entirely prevent water from penetrating through to the foundation; and (4) it does not bond the individual brick together, and so enable them to present a concerted resistance to traffic.

The bituminous fillers vary considerably in quality and efficiency, but all are more or less unsatisfactory. One of the principal objections to their use is based on their tendency to run out of the joints into the gutters during warm weather and to crack and spall out

during cold weather. This tendency can, of course, be partially overcome by exercising proper care in selecting the materials. It should also be noted in their favor that brick pavements, the joints of which have been filled with bituminous preparations, are ordinarily less noisy at first than those in which a Portland cement grout filler has been used. The grout filler is unquestionably very much superior from a standpoint of durability, however, and the excessive noise under traffic which has been frequently observed in connection with its use can be largely eliminated by the use of proper bituminous expansion cushions along the curbs. It is, therefore, recommended as better adapted for filling the joints in brick pavements than any other material which has been commonly used for that purpose.

When the joints of a brick pavement are properly filled with Portland cement grout the individual brick are firmly bonded together and the pavement is thereby practically converted into a monolith. Moreover, since the material composing the joints scarcely wears more rapidly than the brick, the edges of the brick are well protected, and the importance of this feature has already been pointed out.

The most satisfactory method yet devised for mixing and applying the grout filler may be described as follows: Grout boxes constructed in such manner that, when resting on a level platform, one corner will be lower than the others should first be provided. A suitable design for such boxes is shown in Plate II. The number of boxes required depends on the width of the pavement; ordinarily one box to each 10 feet of width will be found sufficient. The grout, which should be put on in two applications, is prepared in batches each of which consists of a quantity of cement not exceeding one sack, a like amount of fine, clean sand, and water. The sand and cement should first be thoroughly mixed dry and sufficient water then admixed to produce a liquid mixture. The consistency of the mixture for the first application should be approximately the same as that of thin cream, and for the second application it should be somewhat thicker.

The pavement should be cleaned and thoroughly sprinkled as a preliminary to making the first application of grout, and it should be kept moist by gentle sprinkling while this application is being made. The grout should be removed from the boxes and spread upon the pavement by means of scoop shovels, and it should be immediately swept into the joints. For this purpose a coarse rattan or fiber push broom should be used in the first application, and a squeegee in the second application. The squeegee is made by clamping a piece of four-ply rubber belting or some other similar material, about 6 by 20 inches in size, between two pieces of board and attaching a suitable handle. The grout in the boxes should be continually stirred until the last shovelful is removed, otherwise a separation of the sand and cement will almost certainly occur.

The first application should proceed about 50 feet in advance of the second. Usually both applications are made by the same crew of laborers. They simply turn back after having covered the allowable distance with the first application and, mixing the grout in the same boxes, bring up the second application. The second application of grout should completely fill the joints flush with the top of the brick.

After the joints are filled as described above and the grout has taken its initial set, the entire surface should be covered to a depth of approximately one-half inch with clean sand. This is done to protect the pavement from the weather and to keep it in a moist condition while the grout is hardening. If necessary, in order to keep the sand moist, it should be occasionally sprinkled for several days after it is spread.

The sand covering should be permitted to remain on the surface for at least 10 days, and during this period the pavement should be kept entirely closed to traffic. If the weather is unfavorable, the length of time during which traffic is kept off the road should be increased.

EXPANSION CUSHIONS.

It has been customary in the past to provide both longitudinal and transverse bituminous expansion cushions in grout-filled brick pavements, but recent practice has demonstrated that the transverse cushions may be advantageously omitted if proper longitudinal cushions are provided. The principal objection to the use of transverse expansion cushions is based on the fact that the material composing the cushions frequently softens during warm weather and runs out toward the curb, thus leaving the edges of the adjoining brick exposed to destructive impact from the wheels of passing vehicles. Even if the cushion consisted of a material which does not run in warm weather, it is necessarily softer than the brick, and the natural result is still the development of unevenness in its immediate vicinity. No such objection can exist concerning longitudinal expansion cushions, however, if they are placed adjacent to the curbs and constructed of proper material. They not only furnish a means for the pavement to expand and contract with changes in temperature but they also eliminate to a large extent the disagreeable rumbling which has been so frequently associated with grout-filled brick pavements.

The bituminous material of which the expansion cushions are made should be such as to remain firm in summer and not to become brittle in winter. It should also possess the quality of durability. In order to insure that any given material is suited for such a purpose, it is usually considered necessary to prescribe certain laboratory requirements to which it must conform, and examples of these, which have

been found to give good results, are contained in the section entitled "Typical specifications." (Cf. p. 21 et seq.)

Expansion cushions should be provided for at the time the brick are laid, by placing a board of the required thickness on edge adjacent to each curb, as shown in figure 3. Small iron wedges, such as are shown in this figure, may be inserted between the curb and the board at the time the board is set. These wedges may be readily loosened and removed after the bricks have been laid and grouted, and may consequently be made to facilitate the removal of the board.

The proper thickness for expansion cushions is a matter concerning which much difference of opinion exists among highway engineers. Some engineers advocate a minimum thickness of 1 inch, while others claim to have secured their best results by using expansion cushions having a minimum thickness as low as three-eighths inch for very narrow pavements. It is generally agreed, however, that the thickness of the cushion should vary with the width of the pavement. The following suggestions for proportioning the cushion are offered as being fairly representative of the best practice.

TABLE 1.—*Ratio of thickness of cushions to width of roadway.*

Width of roadway (feet).	Thickness of cushion (inches).
20 or less	$\frac{1}{2}$
20 to 30	$\frac{3}{4}$
30 to 40	1
Over 40	$1\frac{1}{4}$

Plates III to VII, and Plate VIII, figure 1, show the various steps in the construction of a brick pavement. Plate VIII, figure 2, and Plate IX, figure 1, show the finished pavement as it should appear, and Plate IX, figure 2, shows the advantage possessed by grout-filled joints over joints filled with a soft material.

COST OF BRICK PAVEMENTS.

The cost of brick pavements varies widely, and is affected by so many influences that it is difficult to attempt to derive a general expression showing the relation between probable cost and local conditions. The prices of brick, as also the prices of the various materials entering into the foundation, vary greatly according to the locality and the freight rate. The cost and efficiency of labor is also far from being constant. Furthermore, the material composing the subgrade and the method of preparing it may exert a marked influence on the cost of the pavement. The following statements regarding cost, then, must be considered as representing average conditions, and

FIG. 1.—FINE GRADING.

FIG. 2.—ROLLING.

PREPARING THE SUBGRADE FOR A BRICK ROAD.

FIG. 1.—MIXING CONCRETE FOR THE FOUNDATION.

FIG. 2.—FINISHED CONCRETE FOUNDATION.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

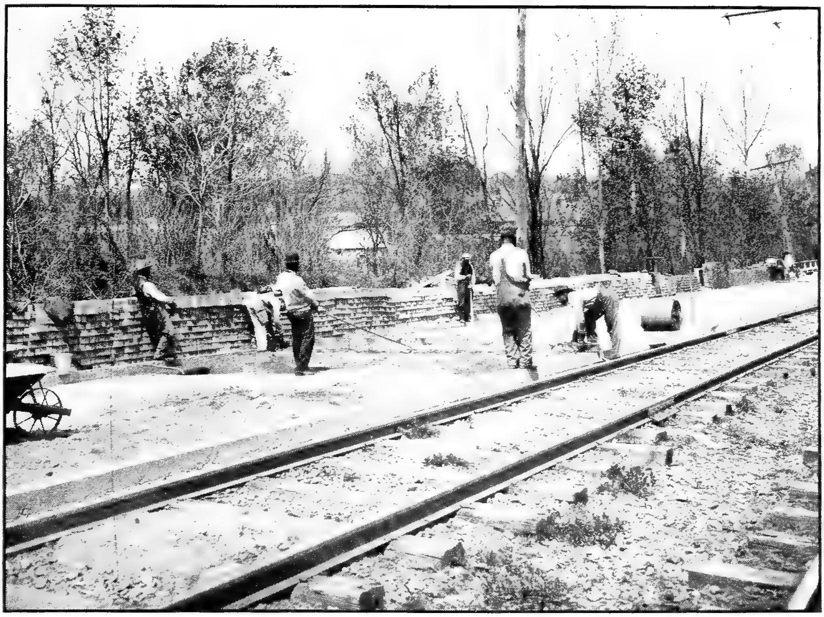


FIG. 1.—SPREADING SAND CUSHION.

FIG. 2.—ROLLING SAND CUSHION.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

FIG. 1.—LAYING THE BRICK

FIG. 2.—ROLLING THE PAVEMENT.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

FIG. 1.—FILLING THE JOINTS, FIRST COAT.

FIG. 2.—FILLING THE JOINTS, SECOND COAT.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

FIG. 1.—FINISHED BRICK PAVEMENT PROTECTED BY SAND COVERING.

FIG. 2.—SHOWING PROPERLY FILLED GROUT JOINTS.

EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

FIG. 1.—EXPERIMENTAL ROAD AT CHEVY CHASE, MD.

Finished pavement in service.

FIG. 2.—GROUT-FILLED BRICK PAVEMENT, HAVING LONGITUDINAL JOINTS IN CENTER AND OCCASIONAL TRANSVERSE JOINTS FILLED WITH SOFT FILLER.

Unsightly appearance at right caused by widening roadway.

care must be exercised in applying them to special cases. They are intended as a guide in preparing estimates of probable cost.

The grading is usually paid for by the cubic yard, and the cost, of course, varies with the character of the soil and the necessary amount of excavation. In light, easily loosened soils, grading may usually be done at from 25 to 40 cents per cubic yard. In hard earth containing more or less loose rock, the cost per cubic yard generally runs from 40 to 75 cents, while grading in solid rock may sometimes cost as much as $1.50 per cubic yard. The cost of the rough grading should be considered entirely apart from the cost of the pavement.

The cost of shaping and rolling the subgrade after the rough grading is completed will ordinarily vary from 3 to 5 cents per square yard. This cost should be included with the other items which make up the cost of the pavement.

The cost of the curbs varies with the character of the material used. Stone curbs ordinarily cost from 25 to 75 cents per linear foot, while curbs made of Portland cement concrete cost, as a rule, from 20 to 50 cents per linear foot. The higher prices for the concrete curbs apply principally to special cases requiring extra form work or considerable extra material.

The cost of the foundation depends largely on the cost of the materials with which it is constructed. Gravel or broken stone can usually be spread and rolled at from 5 to 7 cents per square yard, while the cost of these materials, delivered, varies from $0.60 to $2 per cubic yard. Mixing and placing concrete usually costs from 35 to 75 cents per cubic yard, according to the amount of work to be done and the methods employed, and the cost of the materials, delivered, ordinarily varies from $2.50 to $4.50 per cubic yard of concrete.

The cost of paving brick at the kiln varies from about $12 to $14 per thousand. Estimating 45 brick to the square yard, each 1,000 brick cover approximately 22 square yards, which makes the cost at the kiln per square yard of pavement vary from 55 cents to about 65 cents. These figures mean very little, however, unless the kiln is located conveniently near where the brick are to be used, for freight charges not infrequently amount to more than the cost of the brick.

A force consisting of one paver and five laborers should place on an average about 220 square yards of brick per 10-hour day; while supervision, rolling, and incidental expenses are ordinarily equivalent to the cost of hiring about three and one-half additional laborers.

If C = cost of cement per barrel, S = cost of sand per cubic yard, A = cost of coarse aggregate per cubic yard, B = cost of paving brick per 1,000, and L = cost of labor per hour, with all materials considered delivered on the work and all costs expressed in cents, then the probable cost of constructing a brick pavement, including the

subgrade, a 6-inch concrete foundation, and suitable curbs, may be estimated by substituting in the formula:

$$\text{Cost per square yard} = 1.90\ L + .213\ C + .138\ S + .157\ A + .045\ B.$$

The cost as estimated from this formula should, however, be increased by about 10 per cent to allow for wear on tools and machinery and to guard against unforeseen contingencies. If it is desired to use a different thickness of foundation, it is safe to assume that each inch subtracted or added to the thickness of the foundation will make a corresponding difference of from 8 to 12 cents in the cost per square yard.

MAINTENANCE OF BRICK PAVEMENTS.

If brick pavements are properly constructed at the start, the work of maintaining them is very slight. Under the closest inspection, however, some inferior material is likely to become incorporated either in the foundation or in the surface, and it is, therefore, very important that a brick pavement be very carefully watched for the first few years of its life to see that no unevenness develops either because of defective bricks having been used in the surface or because of insufficient support from the foundation at any point. Whenever any unevenness develops, it should be immediately rectified. Otherwise the pavement will become irregularly worn in the vicinity of the defects and expensive repairs will eventually be necessary.

Not infrequently weak spots develop in broken stone or gravel foundations, owing to surface water finding its way through joints in the pavement which have not been properly filled with grout. Careful observation of the joints should, therefore, constitute a part of the early maintenance work, and any defective joints discovered should be immediately remedied. Where the foundation is constructed of concrete, however, slight defects in the joints seldom result in any very serious damage.

If care is exercised to correct all defects which appear within the first few years of the life of a well-constructed brick pavement, the work of maintaining the pavement proper should thereafter, except for cleaning, be almost negligible. The shoulders and drainage structures, of course, need occasional attention, just as in the case of any other pavement, but if they are properly constructed at the start repairs will usually be very slight.

The life of a well-constructed brick pavement can not be estimated with any great degree of exactness, first, because the traffic conditions are constantly changing, and, second, because no brick pavement which has been constructed in accordance with the best modern practice has yet worn out. The amounts of wear sustained by given pavements during comparatively long periods of years have been

determined in several instances, but have usually been so small as to make the probable terms of service appear almost indefinite. It is evident, however, that in order to secure the full benefit of this excellent resistance to wear the surface of the pavement must not be permitted to become uneven because of the failure of isolated bricks.

TYPICAL SPECIFICATIONS FOR THE CONSTRUCTION OF BRICK ROADS.

Engineer.—The term "engineer," as hereinafter employed, shall be understood to mean the engineer authorized by the officials legally responsible for the proposed improvement. The engineer will furnish all lines and grades, set all necessary stakes, and furnish estimates of the work done upon which to base both partial and final payments. All instructions necessary to give effect to any part of these specifications will be furnished by the engineer, and his decision concerning all matters herein left to his judgment shall be final and conclusive.

Plans and drawings.—All plans and drawings furnished by the engineer which show the general location, profile, details, and dimensions of the proposed road are hereby made a part of these specifications, and the work shall in all respects conform to these plans and drawings, except that such modifications as in the judgment of the engineer are made necessary by the exigencies of construction may be made from time to time. On all drawings figured dimensions are to govern in cases of discrepancy between scale and figures.

Grading and subgrade.—All rubbish, stumps, trees, and other encumbrances which occur on the line of the work shall be removed by the contractor at his own expense.

The roadbed shall be graded to conform to the lines, cross sections, and grades furnished by the engineer. Embankments shall be constructed of a good quality of soil or other material satisfactory to the engineer. They shall be built up in layers not exceeding 12 inches in thickness, and each layer shall be thoroughly compacted by means of a roller weighing not less than 10 tons, or by some other means which the engineer has previously approved.

All soft, spongy, or otherwise objectionable material encountered in preparing the subgrade shall be removed and replaced by other material satisfactory to the engineer. In excavating the contractor shall exercise care not to disturb any material lying beneath the subgrade, as shown on the drawings furnished by the engineer, except in removing objectionable material as above provided.

The entire subgrade shall be rolled with a roller weighing not less than 10 tons, and when complete shall be firm and hard. It shall conform in cross section to the proposed surface of the finished roadway and be at the required depth below it.

Stone curbing.—All stone curbing shall have the shape and size shown on the plans, and shall be hauled and set before the subgrade is completed. The stone used shall be hard, tough, and of a homogeneous texture, and no section of curbing shall have a length less than 4 feet. Stone curbing shall be set true to line and grade, and shall be securely bedded in either broken stone or gravel.

Concrete curbing.—All concrete curbing shall be constructed before the subgrade is completed. It shall have the cross section shown on the plans, and shall be composed of Portland cement concrete, mixed in the proportion 1 part of cement, 2 parts of sand, 4 parts of broken stone or washed gravel, and sufficient water to make a quaky mixture. The specifications as to quality of the materials, mixing and placing the concrete, etc., hereinafter given under "Concrete foundation," shall apply also to concrete curbs.

Forms for concrete curbs shall be constructed of dressed lumber, and the curb shall be constructed in sections not less than 4 feet nor exceeding 12 feet in length. When complete the curb shall present a smooth, neat, uniform appearance, and shall be true to line and grade.

Marginal curb.—Marginal curbs shall be constructed at the ends of the pavement and at all intersections with other roads and driveways. The marginal curbs shall conform to the specifications given above for the kind of curbing employed, except that they shall be shaped to conform to the cross section of the pavement.

Broken stone or gravel foundation.—If a broken stone or gravel foundation is called for, it shall be constructed of sound, durable material, and to the compacted depth shown on the plans. The material shall be well graded in size between that which will just be retained on a screen having ¼-inch circular openings and that which will just pass a screen having 1½-inch circular openings. After the broken stone or gravel has been spread, sufficient clean sand or stone screenings to fill the voids shall be spread over it and flushed in by means of sprinkling and rolling. When completed the foundation shall be well compacted, free from depressions, and uniform in grade and cross section.

Concrete foundation.—If a concrete foundation is called for, it shall be constructed to the depth shown on the plans in the following manner:

The subgrade shall be completed for a distance of at least 50 feet in advance of the foundation work. The foundation shall be constructed of Portland cement concrete mixed in the proportions 1 part of Portland cement, 3 parts of sand, 6 parts of broken stone, and sufficient water to bring the mass to a condition commonly described as quaky. The concrete shall be thoroughly mixed to the satisfaction of the engineer, either by hand or in a mechanical mixer approved

by the engineer, and the materials composing it shall conform to the following requirements:

Cement.—The cement shall be of some standard brand, and shall conform to the United States Government specifications for Portland cement, as contained in Circular 33 of the Bureau of Standards. Cement shall be delivered in sacks of 94 pounds net weight, and each sack shall be considered as having a volume of 1 cubic foot. All sacks which contain lumps or the contents of which have been damaged by exposure to the weather or other cause shall be rejected.

Sand.—The sand shall consist of dry clean quartz grains, and shall not contain more than 5 per cent of clay, loam, or other foreign materials. The grains shall be well graded and of such size that all will pass a ¼-inch mesh screen and not more than 20 per cent will pass a No. 50 sieve.

Coarse aggregate.—The coarse aggregate may consist of either broken stone or gravel. Stone shall be hard and tough, and shall be broken in such manner that all will be retained on a ¼-inch mesh screen and will pass a 1½-inch mesh screen. Not more than 75 per cent of the stone shall pass a ¾-inch mesh screen, and not more than 75 per cent shall be retained on such a screen.

Gravel shall consist of hard, sound particles of stone, thoroughly clean, and shall conform in size to the above specifications for broken stone.

Placing.—The concrete shall be deposited in place immediately after it is mixed and shall be thoroughly compacted as fast as it is placed. The top surface shall be smoothed by troweling with spades or by some other means approved by the engineer, and when completed shall conform to the proposed surface of the finished pavement at the required depth below it.

Time of setting.—The concrete shall be carefully protected from the weather and all other disturbing influences, and kept moist by sprinkling for at least 36 hours after it is placed in the foundation. This period may be increased at the discretion of the engineer. Any damage resulting to the foundation before the wearing surface has been laid, no matter what the cause of such damage may be, shall be repaired by the contractor at his own expense.

Sand cushion.—After the foundation has been constructed and permitted to set as above provided, a layer of sand shall be uniformly spread over the foundation to such depth that when "struck off" and compacted its thickness shall be 2 inches. The sand composing this layer shall be dry when spread and shall conform in all respects to the requirements given above for the sand to be used in concrete. The cushion shall be struck off with a suitable template which conforms to the cross section of the finished pavement, and shall be thoroughly compacted by rolling with a hand roller weighing not less

than 300 pounds. When finished it shall present a smooth, uniform appearance.

The brick.—The brick shall be delivered upon the road and neatly piled outside of the curb lines at such points as are approved by the engineer before the grading is started. The loading, hauling, and unloading shall be carefully done, and at no time shall the brick be thrown, dumped, or in any way roughly handled.

All brick used in the pavement shall be thoroughly vitrified, regular in shape and size, evenly burned, and first class in all other respects. The dimensions shall be 3½ inches in width, 4 inches in depth, and 8½ inches in length, and any brick varying from these dimensions by more than one-half inch in length or by more than one-eighth inch in width or depth shall be rejected. If the edges are rounded, the radius of the curve shall not exceed one-eighth inch. Each brick shall have projections on one side, formed during the process of manufacture, which will serve to produce joints not exceeding one-fourth inch in width and not less than one-eighth inch, when the brick are placed in the pavement.

No brick shall be used in which representative specimens, when subjected to the rattler test recommended by the subcommittee on paving brick of the American Society for Testing Materials [1] lose more than 22 per cent of the original weight of the dried brick composing the charge. In making this test 10 representative bricks shall constitute a charge and, in weighing the rattled brick, no part of a brick weighing less than 1 pound shall be included.

The modulus of rupture for any one representative brick shall not be less than 2,400, and the average modulus of rupture for all bricks tested shall not be less than 2,600. If this test is employed, at least five bricks shall be tested.

Any carload of brick more than 10 per cent of which fails to conform to any of the above requirements shall be rejected. If not more than 10 per cent of a carload fails to meet the requirements, the defective bricks may be picked out and the remainder of the carload used.

Laying the brick.—The brick shall preferably be carried to the pavers on pallets or in clamps and not wheeled in barrows. They shall be laid in straight courses at right angles to the line of the pavement, and if a variation in alignment of more than one one-hundred-and-twentieth the width of the pavement occurs, it shall be corrected by taking up and relaying affected courses.

No parts of brick shall be employed in the pavement except at the beginning and ending of the courses or at other closures. All brick shall be laid with the best edge exposed and as close as possible. After the brick are laid, they shall be carefully inspected and all those

[1] The complete specifications for making this test are given as an appendix to this bulletin.

which are soft, badly spalled, misshapen, or otherwise defective shall be removed and replaced with perfect brick. Kiln-marked brick may be turned over, and if the reverse edge is smooth and no other fault is found, they may remain in the pavement.

The above provision for correcting defects shall not be understood to relieve the contractor from exercising every reasonable precaution to see that only satisfactory brick are correctly placed in the pavement when it is first laid.

After the brick have been laid and inspected as above provided, they shall be brought to a true surface by means of rolling and tamping. The rolling shall be done with a power roller weighing not less than 3 tons nor more than 5 tons and the pavement shall be rolled in both longitudinal and transverse directions. The longitudinal rolling shall begin at the curbs and progress toward the center. The roller shall in all cases cover exactly the same area in making its backward trip which was covered in its forward trip, and shall proceed at a very slow rate until the entire pavement has received the first rolling. The longitudinal rolling shall continue until the brick have been brought to a true surface and are firmly embedded in the sand cushion. The pavement shall then be thoroughly rolled transversely at an angle of 45 degrees with the curb in both directions. Careful inspections shall be made after both the longitudinal and transverse rollings, and all broken or otherwise injured brick shall be removed and replaced to the satisfaction of the engineer.

The brick next to the curb and at other points not readily accessible to the roller shall be brought to a true surface by means of ramming with a hand rammer made of wood and loaded to weigh not less than 80 pounds. The blows of the rammer shall be transmitted through a 2-inch board not less than 5 feet long.

Filling the joints.—The filler shall consist of a grout composed of equal parts of Portland cement and sand, and shall be applied in two coats. The cement shall conform to the specifications hereinbefore given for Portland cement. The sand shall also conform to the specification contained herein for sand to be used in concrete, except that the largest grains shall be required to pass a $\frac{1}{8}$-inch mesh screen instead of a $\frac{1}{4}$-inch mesh screen.

The grout shall be mixed in small batches and not more than one sack of cement to one batch shall be mixed at any one time. The sand and cement shall be thoroughly mixed dry until the mass assumes an even shade of color. Sufficient clean water shall then be admixed to produce a consistency about equal to that of thin cream for the first application, and slightly thicker for the second application. The materials shall be mixed in suitable boxes, which have been approved by the engineer. The legs of each box shall have different lengths, so that the mixture will readily flow to the lowest corner of

the box, which shall be about 6 inches above the pavement. The grout shall be constantly stirred in the boxes until the last of it has been removed and applied to the pavement.

The grout for both applications shall be removed from the boxes and spread over the pavement by means of scoop shovels, and shall be immediately swept into the joints, with a coarse rattan or fiber push broom in the first application and with a squeegee or rubber broom in the second application. The pavement shall have been thoroughly sprinkled before the first application of grout is made and shall be kept moist by means of gentle sprinkling until the grout is spread.

Unless some other arrangement is approved by the engineer, both applications of grout shall be made by the same crew of laborers and with the same appliances. After the first application has advanced about 50 or 60 feet, the second application shall be made. When the second application has been finished, the grout shall entirely fill the joints and shall appear smooth and flush with the surface of the brick.

After the joints have been filled as above provided and the grout has taken its initial set the entire surface of the pavement shall be covered with a ½-inch layer of sand. This sand layer shall be kept moist by sprinkling for at least 3 days and shall remain on the pavement for at least 10 days, and during this period the street shall be entirely closed to traffic. Any damage resulting from traffic or any other disturbing influence which has been prematurely permitted upon the pavement shall be repaired by the contractor at his own expense.

Expansion cushion.—An expansion cushion of the thickness indicated on the plans shall be constructed along each curb as follows:

Suitable provision for the cushions shall be made at the time the brick are laid by setting boards of the proper thickness on edge in the correct position along the curb. After the brick have been laid, rolled, and grouted and the grout has been permitted to harden, the boards shall be removed and the spaces which they occupied shall be filled with either coal-tar pitch or blown-oil asphalt.

If pitch is used, it shall be of such character as to adhere firmly to the paving brick and to the curb and shall be sufficiently plastic to allow for contraction and expansion in the pavement without developing cracks in the joints. It shall contain not less than 25 per cent and not more than 40 per cent of free carbon and shall not contain more than 0.5 per cent of inorganic matter. When tested by the cube method, its melting point shall be not less than 55° C. and not greater than 60° C.

If oil asphalt is used, it shall be soluble in chemically pure carbon disulphide to at least 99 per cent, and when tested by the cube

method its melting point shall be not less than 90° C. and not greater than 110° C. The penetration at 0° C. of a No. 2 needle acting one minute under a weight of 200 grams shall be not less than 2 millimeters. The penetration at 46° C. of a No. 2 needle acting five seconds under a weight of 50 grams shall not exceed 10 millimeters.[1]

When grouting, care shall be exercised to prevent the grout from covering and setting up over this cushion.

CONCLUSION.

Before concluding this discussion of brick pavements, it would seem desirable to emphasize the importance of proper engineering supervision. In the past many communities have expended large sums in efforts to improve their public highways without first having secured the services of some one competent to plan and direct the work. The results have usually been very unsatisfactory under such circumstances and have frequently served to discourage further effort. One of the mistakes most commonly observed consists in constructing some expensive type of pavement on a road where the location is faulty or the grades are impracticable. Not infrequently sharp angles in the alignment or abrupt changes in the grade, which might be easily and inexpensively remedied by an experienced engineer, are left to impede traffic throughout the life of a costly and perhaps durable pavement.

Even in constructing common earth roads it is doubtful economy to dispense with the services of a competent engineer, and if any considerable quantity of work is to be done, such services should certainly be secured. Since brick pavements are probably more expensive to construct than any other type of pavement at present used for country roads, it is all the more important that their construction should be carefully planned and well executed.

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[1] Instead of making a poured joint, as above described, the cushion may be constructed of some of the specially prepared expansion-joint materials. These consist of thin, flexible boards, built up by successive layers of felt and a soft bituminous material. They can be obtained with a width approximately the depth of a brick, and a sufficient number of them to make the proper thickness of cushion are set on edge along the curb when the brick are laid.

APPENDIX.

METHOD FOR INSPECTING AND TESTING PAVING BRICK.[1]

The quality and acceptability of paving brick, in the absence of other special tests mutually agreed upon in advance by the seller on the one side and the buyer on the other side, shall be determined by the following procedure, viz:

(1) *The rattler test*, for the purpose of determining whether the material as a whole possesses to a sufficient degree, strength, toughness, and hardness;

(2) *Visual inspection*, for the purpose of determining whether the physical properties of the material as to dimensions, accuracy and uniformity of shape and color are in general satisfactory, and for the purpose of culling out from the shipment individually imperfect or unsatisfactory brick.

The acceptance of paving bricks as satisfactorily meeting one of these tests shall not be construed as in any way waiving the other.

SECTION I.—THE RATTLER TEST.

THE SELECTION OF SAMPLES FOR TEST.

ITEM 1. *Place of sampling.*—In general where a shipment of bricks involving a quantity of less than 100,000 is under consideration, the sampling may be done either at the brick factory prior to shipment, or on cars at their destination or on the street, when delivered ready for use. When the quantity under consideration exceeds 100,000, the sampling shall be done at the factory prior to shipment. Bricks accepted as the result of tests prior to shipment shall not be liable to subsequent rejection as a whole, but are subject to such culling as is provided for under Section II (Visual inspection).

ITEM 2. *Method of selecting samples.*—In general the buyer shall select his own samples from the material which the seller proposes to furnish. The seller shall have the right to be present during the selection of a sample. The sampler shall endeavor, to the best of his judgment, to select brick representing the average of the lot. No samples shall include bricks which would be rejected by visual inspection as provided in Section II, except that where controversy arises, whole tests may be selected to determine the admissibility of certain types or portions of the lot having a characteristic appearance in common. In cases where prolonged controversy occurs between buyer and seller and samples selected by each party fail to show reasonable concurrence, then both parties shall unite in the selection of a disinterested person to select the samples, and both parties shall be bound by the results of samples thus selected.

ITEM 3. *Number of samples per lot.*—In general one sample of ten bricks shall be tested for every 10,000 bricks contained in the lot under consideration, but where the total quantity exceeds 100,000, the number of tests tested may be fewer than one per 10,000, provided that they shall be distributed as uniformly as practicable over the entire lot.

ITEM 4. *Shipment of samples.*—Samples which must be transported long distances by freight or express must be carefully put up in packages holding not more than 12 bricks each. When more than six bricks are shipped in one package, it must be so arranged as to carry two parallel rows of bricks side by side, and these rows must be separated by a partition. In event of some of the bricks being cracked or broken in transit, the sample shall be disqualified if there are not remaining ten sound undamaged bricks.

[1] Recommended by subcommittee on paving brick of the American Society for Testing Materials.

ITEM 5. *Storage and care of samples.*—Samples must be carefully handled to avoid breakage or injury. They must be kept dry so far as practicable. If wet when received, or known to have been immersed or subjected to recent prolonged wetting, they shall be dried for at least six hours in a temperature of 100° Fahrenheit before testing.

THE CONSTRUCTION OF THE RATTLER.

ITEM 6. The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of materials and dimensions, and shall consist of barrel, frame and driving mechanism as herein described. Accompanying these specifications is a complete drawing (Pl. X) of a rattler which will meet the requirements, and to which reference should be made.

ITEM 7. *The barrel.*—The barrel of the machine shall be made up of the heads and headliners, and staves and stave-liners.

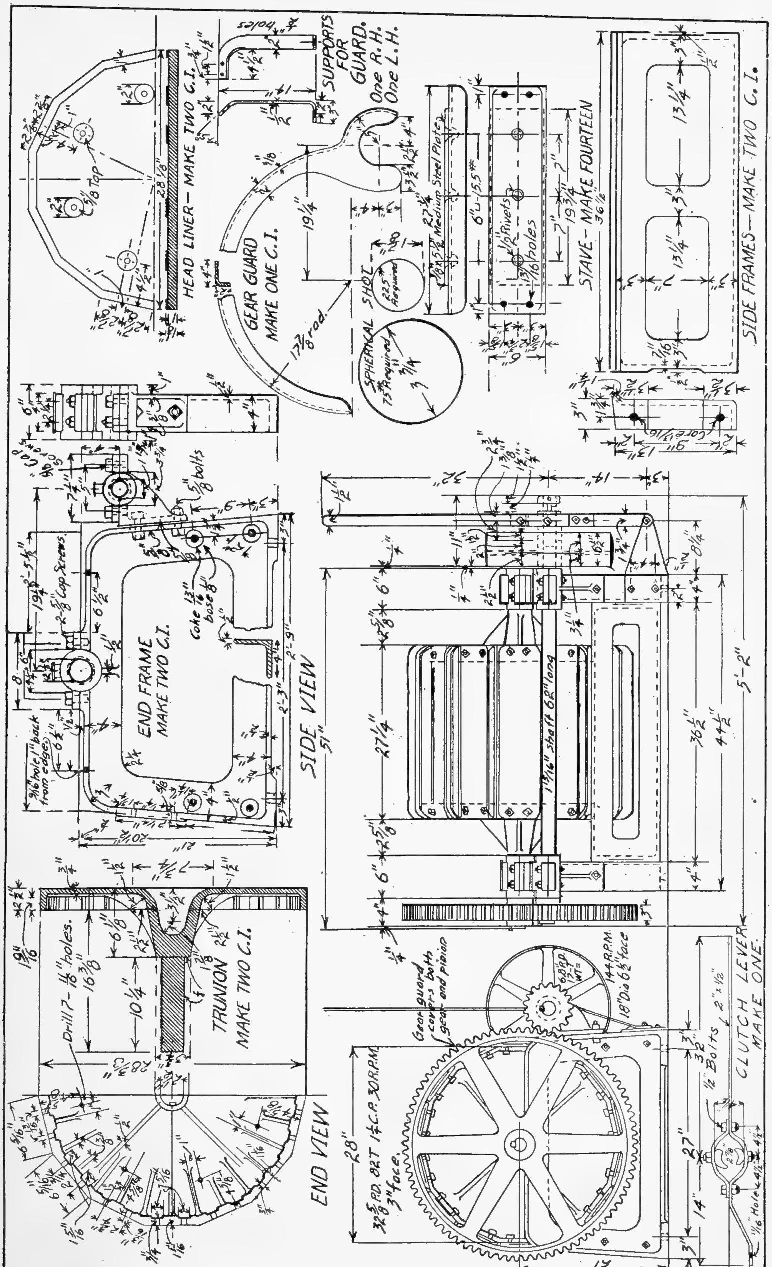
The heads may be cast in one piece with the trunnions, which shall be $2\frac{1}{2}$ inches in diameter, and shall have a bearing 6 inches in length, or they may be cast with heavy hubs, which shall be bored out for $2\frac{7}{16}$-inch shafts, and shall be keyseated for two keys, each $\frac{1}{2}$ inch by $\frac{3}{8}$ inch and spaced 90 degrees apart. The shaft shall be a snug fit and when keyed shall be entirely free from lost motion. The distance from the end of the shaft or trunnion to the inside face of the head shall be $15\frac{3}{8}$ inches in the head for the driving end of the rattler, and $11\frac{3}{8}$ inches long for the other head, and the distance from the face of the hubs to the inside face of the heads shall be $5\frac{1}{2}$ inches.

The heads shall be not less than $\frac{3}{4}$ inch nor more than $\frac{7}{8}$ inch thick. In outline, each head shall be a regular 14-sided polygon inscribed in a circle $28\frac{3}{8}$ inches in diameter. Each head shall be provided with flanges not less than $\frac{3}{4}$ inch thick and extending outward $2\frac{1}{2}$ inches from the inside face of the head to afford a means of fastening the staves. The surface of the flanges of the head must be smooth and must give a true and uniform bearing for the staves. To secure the desired true and uniform bearing the surfaces of the flanges of the head must be either ground or machined. The flanges shall be slotted on the outer edge, so as to provide for two $\frac{3}{4}$-inch bolts at each end of each stave, said slots to be $\frac{13}{16}$ inch wide and $2\frac{3}{4}$ inches, center to center. Each slot shall be provided with a recess for the bolt head, which shall act to prevent the turning of the same. Between each two slots there shall be a brace $\frac{5}{8}$ inch thick, extending down the outward side of the head not less than 2 inches.

There shall be for each head a cast-iron headliner 1 inch in thickness and conforming to the outline of the head, but inscribed in a circle $28\frac{1}{8}$ inches in diameter. This headliner shall be fastened to the head by seven $\frac{5}{8}$-inch cap screws, through the head from the outside. Whenever these headliners become worn down $\frac{1}{2}$ inch below their initial surface level at any point of their surface, they must be replaced with new ones. The metal of these headliners shall be hard machinery iron and should contain not less than 1 per cent of combined carbon.

The staves shall be made of 6-inch medium steel structural channels $27\frac{1}{4}$ inches long and weighing 15.5 pounds per lineal foot. The staves shall have two holes $\frac{13}{16}$ inch in diameter, drilled in each end, the center line of the holes being 1 inch from the end and $1\frac{3}{8}$ inches either way from the longitudinal center line. The spaces between the staves shall be as uniform as practicable, but must not exceed $\frac{5}{16}$ inch.

The interior or flat side of each stave shall be protected by a liner $\frac{3}{8}$ inch thick by $5\frac{1}{2}$ inches wide by $19\frac{3}{4}$ inches long. The liner shall consist of medium steel plate and shall be riveted to the channel by three $\frac{1}{2}$-inch rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced 7 inches from the center each way. The rivet holes shall be countersunk on the face of the liner and the rivets shall be driven hot and chipped off flush with the surface of the liners. These liners shall be inspected from time to time, and if found loose shall be at once reriveted, but no liner shall be replaced by a new one except as the whole set is changed.



PLAN FOR RATTLER.

Any test at the expiration of which a stave-liner is found detached from the stave or seriously out of position shall be rejected. When a new set of liners has been placed in position, before being used for testing, the rattler shall be charged with 400 pounds of shot of the same sizes, and in the same proportions as provided in Item 9 and shall then be run for 1,800 revolutions at the usual prescribed rate of speed. The shot shall then be removed and a standard shot charge inserted, after which the rattler may be charged with brick for a test.

No set of liners shall be used for more than one hundred tests. The record must show the date when each set of liners goes into service, and the number of tests made upon each set.

The staves when bolted to the heads shall form a barrel 20 inches long, inside measurement, between headliners. The liners of the staves must be so placed as to drop between the headliners. The staves shall be bolted tightly to the heads by four $\frac{3}{4}$-inch bolts, and each bolt shall be provided with a lock nut, and shall be inspected at not less frequent intervals than every fifth test and all nuts shall be kept tight. A record shall be made after each inspection showing in what condition the bolts were found.

Item 8. *The frame and driving mechanism.*—The barrel shall be mounted on a cast-iron frame of sufficient strength and rigidity to support it without undue vibration. It shall rest on a rigid foundation with or without the interposition of wooden plates and shall be fastened thereto by bolts at not less than four points.

It shall be driven by gearing whose ratio of driver to driven is not less than one to four. The counter shaft upon which the driving pinion is mounted shall not be less than $1\frac{15}{16}$ inches in diameter, with bearings not less than 6 inches in length. It shall be belt-driven, and the pulley shall not be less than 18 inches in diameter and $6\frac{1}{2}$ inches in face. A belt of 6-inch double-strength leather, properly adjusted, to avoid unnecessary slipping, should be used.

Item 9. *The abrasive charge.*—The abrasive charge shall consist of cast-iron spheres of two sizes. When new, the larger spheres shall be 3.75 inches in diameter and shall weigh approximately 7.5 pounds (3.40 kilos) each. Ten spheres of this size shall be used.

These shall be weighed separately after each ten tests, and if the weight of any large sphere falls to 7 pounds (3.175 kilos), it shall be discarded and a new one substituted, provided, however, that all of the large spheres shall not be discarded and substituted by new ones at any single time, and that so far as possible the large spheres shall compose a graduated series in various stages of wear.

When new, the smaller sized spheres shall be 1.875 inches in diameter and shall weigh approximately 0.95 pound (0.43 kilo) each. In general the number of small spheres in a charge shall not fall below 245 nor exceed 260. The collective weight of the large and small spheres shall be as nearly as possible 300 pounds. No small sphere shall be retained in use after it has been worn down so that it will pass a circular hole 1.75 inches in diameter, drilled in an iron plate $\frac{1}{4}$ inch in thickness, or weigh less than 0.75 pound (0.34 kilo). Further, the small spheres shall be tested by passing them over the above plate, or shall be weighed after every ten tests, and any which pass through or fall below the specified weight shall be replaced by new spheres, and provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small sphere shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon	Not less than 2.50 per cent.
Graphitic carbon	Not more than 0.25 per cent.
Silicon	Not more than 1.00 per cent.
Manganese	Not more than 0.50 per cent.
Phosphorus	Not more than 0.25 per cent.
Sulphur	Not more than 0.08 per cent.

For each new batch of spheres used, the chemical analysis must be furnished by the maker or be obtained by the user, before introducing into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

THE OPERATION OF THE TEST.

ITEM 10. *The brick charge.*—The number of brick per test shall be ten for all bricks of so-called "block size," whose dimensions fall between from 8 to 9 inches in length and $3\frac{3}{4}$ inches to $4\frac{1}{4}$ inches in thickness.[1] No brick should be selected as part of a regular test that would be rejected by any other requirements of the specifications under which the purchase is made.

ITEM 11. *Speed and duration of revolution.*—The rattler shall be rotated at a uniform rate of not less than $29\frac{1}{2}$ nor more than $30\frac{1}{2}$ revolutions per minute, and 1,800 revolutions shall constitute the test. A counting machine shall be attached to the rattler for counting the revolutions. A margin of not to exceed ten revolutions will be allowed for stopping. Only one start and stop per test is generally acceptable. If from accidental causes, the rattler is stopped and started more than once during a test, and the loss exceeds the maximum permissible under the specifications, the test shall be disqualified and another made.

ITEM 12. *The scales.*—The scales must have a capacity of not less than 300 pounds, and must be sensitive to one-half of an ounce, and must be tested by a standard test weight at intervals of not less than every ten tests.

ITEM 13. *The results.*—The loss shall be calculated in percentage of the initial weight of the brick composing the charge. In weighing the rattled brick, any piece weighing less than one pound shall be rejected.

ITEM 14. *The records.*—A complete and continuous record shall be kept of the operation of all rattlers working under these specifications. This record shall contain the following data concerning each test made.

1. The name of the person, firm or corporation furnishing each sample tested.
2. The name of the maker of the brick represented in each sample tested.
3. The name of the street, or contract which the sample represented.
4. The brands or marks upon the bricks, by which they were identified.
5. The number of bricks furnished.
6. The date on which they were received for test.
7. The date on which they were tested.
8. The drying treatment given before testing, if any.
9. The length, breadth and thickness of the bricks.
10. The collective weight of the 10 large spherical shot used in making the test at the time of their last standardization.
11. The number and collective weight of the small spherical shot used in making the test, at the time of their last standardization.
12. The total weight of the shot charge, after its last standardization.
13. Certificate of the operator that he examined the condition of the machine as to staves, liners, and any other parts affecting the barrel, and found them right at the beginning of the test.
14. Certificate of the operator of the number of charges tested since the last standardization of shot charge.
15. Certificate of the operator of the number of charges tested since the stave liners were renewed.
16. Certificate of the operator that the requisite number of revolutions were made, under the prescribed conditions, upon the staves after the last relining, before a brick test was made.

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[1] Where brick of larger or smaller sizes than the dimensions given above for blocks are to be tested, the same number of bricks per charge should be used, but allowance for the difference in size should be made in setting the limits for average and maximum rattler loss.

17. The time of the beginning and ending of each test, and the number of revolutions made by the barrel during the test as shown by the indicator.

18. Certificate of the operator as to number of stops and starts made in each test.

19. The initial collective weight of the ten bricks composing the charge and their collective weight after rattling.

20. The loss calculated in percents of the initial weight; and the calculation itself.

21. The number of broken bricks and remarks upon the portions which were included in the final weighing.

22. General remarks upon the test and any irregularities occurring in its execution.

23. The date upon which the test was made.

24. The location of the rattler and name of the owner.

25. The certificate of the operator that the test was made under the specifications of the American Society for Testing Materials and that the record is a true record.

26. The signature of the operator or person responsible for the test.

27. The serial number of the test.

In event of more than one copy of the record of any test being required, they may be furnished on separate sheets, and marked duplicates, but the original record shall always be preserved intact and complete.

ACCEPTANCE AND REJECTION OF MATERIAL.

ITEM 15. *Basis of acceptance or rejection.*—Paving bricks shall not be judged for acceptance or rejection by the results of individual tests, but by the average of no less than five tests. Where a lot of bricks fail to meet the required average, it shall be optional with the buyer whether the bricks shall be definitely rejected or whether they may be regraded and a portion selected for further test as provided in Item 16.

ITEM 16. *Range of fluctuation.*—Some fluctuation in the results of the rattler test, both on account of variation in the bricks and in the machine used in testing, are unavoidable and a reasonable allowance for such fluctuations should be made, wherever the standard may be fixed.

In any lot of paving brick, if the loss on a test computed upon its initial weight exceeds the standard loss by more than 2 per cent, then the portion of the lot represented by that test shall at once be resampled and three more tests executed upon it, and if any of these three tests shall again exceed by more than 2 per cent the required standard, then that portion of the lot shall be rejected.

If in any lot of brick two or more tests exceed the permissible maximum, then the buyer may at his option reject the entire lot, even though the average of all the tests executed may be within the required limits.

ITEM 17. *Fixing of standards.*—The percentage of loss which may be taken as the standard will not be fixed in these regulations, and shall remain within the province of the contracting parties. For the information of the public, the following scale of average losses is given, representing what may be expected of tests executed under the foregoing specifications.

	General average loss.	Maximum permissible loss.
	Per cent.	*Per cent.*
For bricks suitable for heavy traffic	22	24
For bricks suitable for medium traffic	24	26
For bricks suitable for light traffic	26	28

Which of these grades should be specified in any given district and for any given purpose is a matter wholly within the province of the buyer, and should be governed by the kind and amount of traffic to be carried, and the quality of paving bricks available.

ITEM 18. *Culling and retesting.*—Where, under Items 15 and 16 a lot or portion of a lot of brick is rejected, either by reason of failure to show a low enough average test or because of tests above the permissible maximum, the buyer may at his option permit the seller to regrade the rejected brick, separating out that portion which he considers at fault and retaining that which he considers good. When the regrading is complete, the good portion shall be then resampled and retested, under the original conditions, and if it fails again either in average or in permissible maximum, then the buyer may definitely and finally reject the entire lot of portion under test.

ITEM 19. *Payment of cost of testing.*—Unless otherwise specified, the cost of testing the material as delivered or prepared for delivery, up to the prescribed number of tests for valid acceptance or rejection of the lot, shall be paid by the buyer. (See also Item 23.) The cost of testing extra samples made necessary by the failure of the whole lot or any portion of it, shall be paid by the seller, whether the material is finally accepted or not.

SECTION II.—VISUAL INSPECTION.

It shall be the right of the buyer to inspect the bricks, subsequent to their delivery at the place of use, and prior to or during laying, to cull out and reject upon the following grounds:

ITEM 20. All bricks which are broken in two or chipped in such a manner that neither wearing surface remains intact, or that the lower or bearing surface is reduced in area by more than one-fifth. Where brick are rejected upon this ground, it shall be the duty of the purchaser to use them so far as practicable in obtaining the necessary half bricks for breaking courses and making closures, instead of breaking otherwise whole and sound brick for this purpose.

ITEM 21. All bricks which are cracked in such a degree as to produce defects such as defined in Item 20, either from shocks received in shipment and handling, or from defective conditions of manufacture, especially in drying, burning or cooling, unless such cracks are plainly superficial and not such as to perceptibly weaken the resistance of the brick to its conditions of use.

ITEM 22. All bricks which are so off-size, or so misshapen, bent, twisted or kiln-marked, that they will not form a proper surface as defined by the paving specifications, or align with other bricks without making joints other than those permitted in the paving specifications.

ITEM 23. All bricks which are obviously too soft and too poorly vitrified to endure street wear. When any disagreement arises between buyer and seller under this Item, it shall be the right of the buyer to make two or more rattler tests of the brick which he wishes to exclude, as provided in Item 2, and if in either or both tests, the bricks fall beyond the maximum rattler losses permitted under the specifications, then all bricks having the same objectionable appearance may be excluded, and the seller must pay for the cost of the test. But if under such procedure, the bricks which have been tested as objectionable shall pass the rattler test, both tests falling within the permitted maximum, then the buyer cannot exclude the class of material represented by this test and he shall pay for the cost of the test.

ITEM 24. All bricks which differ so markedly in color from the type or average of the shipment as to make the resultant pavement checkered or disagreeably mottled in appearance. This Item shall not be held to apply to the normal variations in color which may occur in the product of one plant among bricks which will meet the rattler test as referred to in Items 15, 16, and 17, but shall apply only to differences of color which imply differences in the material of which the bricks are made, or extreme differences in manufacture.

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